STUDY OF EMITTER MATERIALS FOR USE IN HOSTILE ENVIROMENTS

W. A. Mackie, C. Dandeneau, L.A. Southall,
and F. M. Charbonnier
Applied Physics Technologies, Inc., McMinnville, OR 97128

ABSTRACT

We have investigated several materials for use as deposited field emitters for arrays. The rationale for this study has been to develop field emitter arrays for use at high pressures, in hostile gas environments, and operation at high emitted-current levels. Emitters have been made and tested with several refractory carbide materials including niobium carbide[1], titanium carbide, and zirconium carbide[2,3] We found carbide materials resistant to sputtering, to poor vacuum conditions, and to environments where oxygen ambient is required as in thrusters. We have also taken another track and vapor deposited film combinations from refractory elements that are resistant to oxidation as well as from metals which readily oxidize but have stable, conducting oxides.

Electron beam heated physical vapor deposition was used throughout with deposition rates of 0.1 to 0.5 nm/s depending upon the material. Vacuum conditions during deposition were carefully monitored to avoid inclusion of excessive amounts of oxygen. Substrates for these experiments were Si wafers for the planar film study and proprietary field emitter array blanks for the emitter work. Typical deposition techniques used ~10 nm of Ti as a bonding layer followed by ~300 nm of a base material were used and followed immediately by ~10 nm of a top material. Surfaces of carbides, oxide resistant metals, and metals with conductive oxides were deposited in this manner. Table I summarizes the materials used in the planar study. For emitter fabrication NbC/Nb[1], TiC/Ti, and ZrC/Mo have been studied to date.

Table I: Emitter materials examined.

Wafer#	Material	Thickness and Notes
1	NbC/Nb	10 nm NbC/500 nm NbC
2	Mo/ZrC	10 nm ZrC/300 nm Mo
3	Ru/Ta	10 nm Ru/300 nm Ta
4	Ru/Ta	10 nm Ru-Ta co-dep./300 nm Ta
5	C/Pt	10 nm layered Pt-C/300 nm Pt
6	NiNb/Nb	10 nm Ni-Nb co-dep./300 nm Nb
7	Mg/Pt	200 nm of co-dep. Pt-Mg
8	Nb	300 nm
9	Pt	200 nm
10	Ta	300 nm

After deposition the samples were removed for later study. The examination system for the planar film samples consisted of a UHV chamber fitted with several instruments including a fixed-beam Auger analyzer and a monochrometer for use in determining surface work function via photoelectron emission. The emitters were studied in a moderate-vacuum system as described elsewhere[1].

The photoelectron current is measured for varying photon energies as determined by the monochrometer. These data are plotted in a Fowler plot which is the square-root of the quantum efficiency vs. the photon energy. Plotting in this manner yields a linear section of the curve which one can extrapolate the photon energy at zero yield. This value is an indication of the work function of the surface as one can see from examination of the Fowler equation,

$$Q.E. = C(h\nu - \phi)^2$$

Where Q.E is the quantum efficiency, C the Fowler constant, the quantity (hν) the photon energy, and ϕ is the surface work function. A typical Fowler plot is shown in Fig. 1.

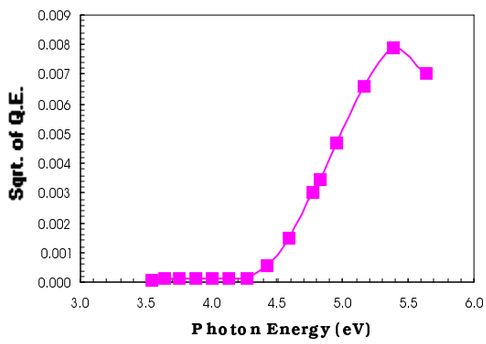

Figure 1: Fowler plot of Ru on Ta (wafer # 3) several hours after evacuation in the UHV sample examination system. Note this plot yields an approximate value for the surface work function of 4.4 eV.

We will present the results obtained for all samples and evaluate their utility as an electron source for field emitter arrays particularly for use in oxygen environments.

Data are also summarized on emission testing of arrays fabricated with Nb, NbC/Nb, and other carbides which confirm the benefit of using carbide materials where lower turn-on voltages and increased emission stability were realized over emitters made solely from refractory metals (see Fig. 2). For high current operation, one emission test recorded currents from a single niobium carbide emitter in excess of 1 mA. These and other emission testing results will be presented.

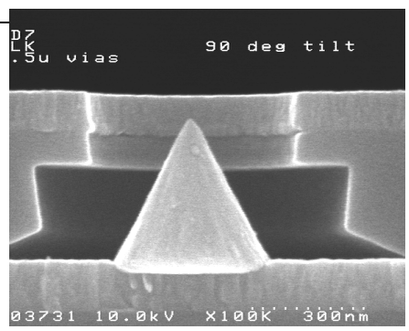

Figure 2: SEM image of a cleaved Nb array cathode.

REFERENCES:

[1] W. A. Mackie, L. A. Southall, Tianbao Xie, G. L. Cabe, and P. H. McClelland, "Emission characteristics of NbC/Nb field emitter array cathodes," Paper delivered and submitted for publication at IVMC'01, Davis, CA, (Aug. 2001).

[2] W. A. Mackie, Tianbao Xie, and P.R. Davis, "Transition metal carbide field emitters for FEA devices and high current applications," *Journal of Vacuum Science and Technology B*, **17** (2) 613 (1999).

[3] F.M. Charbonnier, W.A. Mackie, L.A. Southall, and R.L. Hartman, "Niobium carbide field emitter array and focusing study for vacuum microelectronics," Paper delivered and submitted for publication at EuroFE01, Alicante, Spain, Nov. (2001).